Integrating Systems Engineering Simulations for Military Use

Kevin Tang, Glenn Beach, Charles Cohen,
Ryan O'Grady, Rudy Rodriguez, Steve Rowe
381@cybernet.com
Cybernet Systems Corporation

Rakesh Patel, Jason Ueda, Eric Jochum,
Syed Mohammad
U.S. Army Tank Automotive Research Development and Engineering Command (TARDEC)

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Abstract

The U.S. Department of Defense (DoD) relies on a multitude of fragmented simulations to assist in engineering new systems. The DoD has recognized the need for unified simulation environments to enhance the value of new models and help achieve its defense transformation goals; a major example of this is the U.S. Army's OneSAF program. However, no plan exists to leverage the thousands of simulation models that remain idle on shelves. Localized efforts by the government and its contractors to unify such models have been marginalized by a number of technical and non-technical hurdles, some of which are not obvious. These include the availability of models, the usability of simulation construction tools, the creation of reference architecture, the complexity of simulation results, the automation of repetitive integration tasks, and the verification and validation of component models, among others.

This paper discusses these hurdles in greater detail and provides context to DoD simulation efforts from the team developing the Virtual Systems Integration Lab (VSIL) for the U.S. Army TARDEC. We conclude with recommendations for establishing a unified approach to maximize simulation reuse across the DoD.

1. BACKGROUND

Historically, the development lifecycle of most major U.S. Department of Defense (DoD) acquisition and R&D programs can be categorized as stovepipe efforts that operate independently of each other and often in parallel. As a result, the DoD relies on a multitude of fragmented simulations to assist in engineering new systems. Consequently, many of these simulations were duplications of effort. The DoD began to recognize the value of unified simulation environments to enhance the utility of new models and achieve its defense transformation goals. A major example of this was the U.S. Army's OneSAF program, designed to integrate multi-domain simulations into one. The DoD's overall goal for simulation-based engineering is to field the best systems for the future military force in the shortest time using the fewest resources.

While the DoD recognizes the need to integrate modeling and simulation (M&S) test environments to maximize value and achieve its goals, no plan exists to leverage the thousands of existing simulation models that remain idle in DoD's M&S portfolio. Localized efforts by the government and its contractors to unify such models have been marginalized by a number of technical and non-technical hurdles, some of which are not obvious. The first step to unifying such simulations in a useful manner is to define what that goal means.

2. DEFINTION OF UNIFIED SIMULATION

Unified simulation is an ambitious goal for Systems Engineering that will be reached once the following criteria and capabilities are satisfied and delivered:

- Interoperability standards allow any compliant simulation method to be incorporated (e.g., HLA, OneSAF)
- All standalone simulation models can be integrated as pieces of a bigger puzzle (e.g., Matlab, Simulink, C++)
- A global simulation picture provides the ability to "zoom in" on any level of detail ranging from systems to sub-components
- System design feedback gets generated that accelerates feasibility testing of hardware and software

3. REAL-LIFE EXAMPLE

A real-life example of an effort to unify systems engineering as defined above is the Virtual System Integration Lab (VSIL) program under the U.S. Army Tank Automotive Research, Development & Engineering Center (TARDEC). VSIL is a simulation suite for accelerating systems engineering that tests prototype designs prior to committing to a physical prototype. Cybernet was contracted to develop the software architecture and model-based design methodology of the VSIL.

3.1. VSIL Concept & Strategy

The VSIL system uses "lego-like" soft building blocks that can be dragged from a component model library to easily configure a complex system for simulation. The initial focus was on the development of simulation models that could precisely mimic the software electrical system hardware of a vehicular platform (e.g., the electrical power system architecture containing the wiring harness, actuator

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motors/solenoids, and sensors). The various components of the system (i.e., the wiring harness, actuator motors/solenoids, sensors) would be the basic building blocks. These components would model the hardware and software from the functional point of view.

The goal was to use these virtual components and create the complete electrical system for the vehicle, and study its behavior. Later, the scope of the work was extended to other sub-systems beyond the electrical system, thus leading the way to a complete virtual vehicle build.

A key provision of the VSIL was to allow users to add to the library of modules with appropriate input/output definitions, to enrich the module library as needed. This enabled a workflow for new systems design that leveraged existing component models to develop future systems, as illustrated in Figure 1.

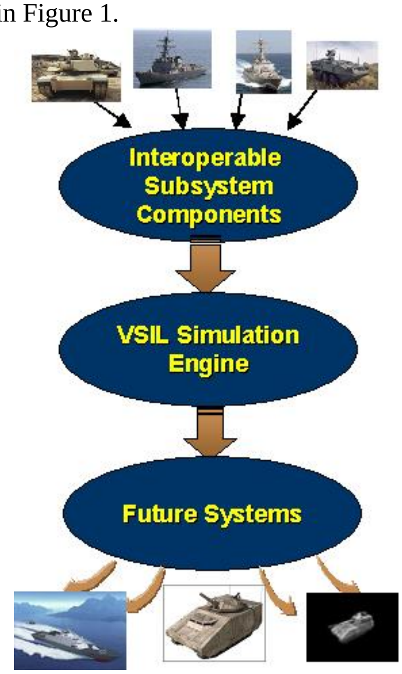

Figure 1. VSIL process for new systems design

Currently there exist generic tools in the market that are basically standard CAE (computer-aided engineering) software packages. These generic CAE tools, however, do not offer the advantage of catering to alternative system designs easily. They do not use "soft" modular lego-like components, so that a complete system or sub-system can be quickly and easily "assembled," virtually "built," and virtually "run" by any ordinary user.

3.2. VSIL Objectives

The objectives of the VSIL were the following:

- Accelerate and enhance next-generation vehicle design and development
- Increase efficiency of simulation development
- Perform cost-benefit analysis on component models up to full deployments
- Transform development process so that new vehicle designs benefit from the development of all previous vehicles

3.3. Virtual Systems Editor (ViSE)

Cybernet has created the capstone tool of the VSIL called the Virtual Systems Editor, dubbed the "ViSE." The ViSE automates the creation, execution, and analysis of trade-off studies. With the ViSE, the VSIL has achieved a degree of unified simulation, according to our definition:

- The ViSE interoperates with simulation models via HLA and VSIL Reference Architecture standards.
- The ViSE leverages standalone simulation models for components and subsystems from Matlab, Simulink, C/C++, and Java.
- The ViSE enables the user to observe the system-level to component-level views of the systems being configured.
- The ViSE logs data from the simulation to enable system design analysis based on the given scenario. This data enables automated component trade-off analysis and requirements generation.

Post-analysis tools are in development and are modeled in Figure 2. Using the ViSE, a user can experiment with different configurations based on a given scenario and a library of models. A screenshot of the ViSE is Figure 3.

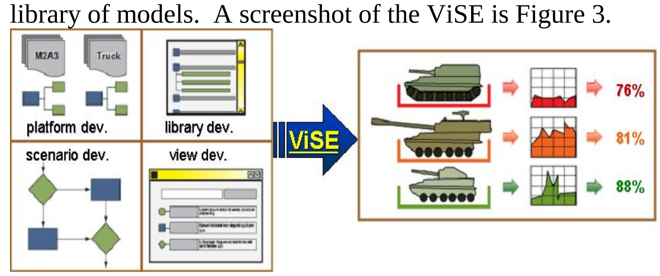

Figure 2. ViSE workflow

Figure 3. ViSE software version 0.5

4. HURDLES TO UNIFIED SIMULATION

The VSIL team encountered the following hurdles during its joint simulation efforts with TARDEC:

- The availability of models
- The usability of simulation construction tools
- The creation of reference architecture
- The complexity of simulation results
- The automation of repetitive integration tasks
- The verification and validation of component models

4.1. The availability of models

The credibility of M&S is tied to the availability and fidelity of the component models of interest (e.g., Mobility, Suspension). We found that populating a useful model library from scratch was a lengthy task that requires vast domain expertise.

To overcome this hurdle, we added staff to the VSIL team with vehicle systems expertise and sought out existing models from TARDEC.

4.2. The creation of Reference Architecture (RA)

RA defines the interfaces required by models to be leveraged into a unified simulation (e.g., RA for vehicle electronics component includes technical and non-technical attributes such as power consumption and component cost). We found that creating RA was an exhausting task. A mature RA required perpetual re-factoring over time.

To overcome this hurdle, we refreshed the RA iteratively rather than constantly, after we completed major demonstration milestones.

4.3. The verification & validation of simulation models

True validation of models was only possible by using real data taken from the component or system being modeled, or by using the most high-fidelity models available. However, those models were not available to DoD engineers or contractors. Additionally, verification and validation required definitions for "high-fidelity" models and tiers of model fidelity.

To overcome this hurdle, we established definitions and criteria for judging model fidelity in documents pending approval.

4.4. The complexity of simulation and results

As systems were modeled and simulated at higher fidelity, the simulations produced progressively larger sets of data. For example, swapping out five different types of components with two models each produced thirty-two (2^5) iterations to execute. Adding one more type of component to trade-off doubled the number of iterations to sixty-four, etc. This doubled the time it took to execute the simulations in batch. Using higher fidelity simulations models further prolonged the total execution time. Processing the output data sets in meaningful ways was also time-consuming. We needed better analysis tools to process output data faster.

To overcome these hurdles, we simplified and shortened the test scenarios in a piecewise manner. We also added provisions to end the execution of scenarios earlier if key aspects of the system failed, such as an engine stall.

4.5. The usability of simulation construction tools

The usability of tools impacts the efficiency of model verification and validation. User-friendly tools encourage more use, reduce anxiety, and build confidence.

The typical users of the VSIL and ViSE were not professional software developers, but basic computer users with mechanical and electrical engineering backgrounds. Other users were managers who controlled budgets and made acquisition decisions.

To address the needs of such users, we included step-by-step instructions on running pre-made demonstrations with pointers on what to observe while walking through the software tools. We also invested a significant amount of time in showing the tools to the users in person, so that more questions could be immediately addressed.

4.6. The automation of repetitive integration & analysis tasks

Automating as much of the simulation workflow as possible was key to achieving the benefits of unified simulation. The automated model wrapping for common formats was highly desired. The automated formatting and analysis of output data was equally desired.

To address these concerns, we wrote technical recommendations for solving the automatic model-wrapping problem with various formats, including HLA, C/C++, Java, and Matlab/Simulink. We also customized Perl scripts to create trend plot overlays for each test point. These scripts processed the post-simulation data in a format more easily consumed by Microsoft Excel. In addition, we used spreadsheet macros to update a summary report and ranking of results.

5. CONCLUSIONS FOR MILITARY SIMULATION

Simulation-based engineering is a vital but expensive enterprise. Unified simulation is an ambitious goal that will accelerate innovation and make systems engineering more viable in the long run. Government leadership will help overcome the hurdles to unifying military systems engineering simulations.

The DoD is the only organization that can truly unify systems engineering simulations for military use. Relying solely on industry and non-profits like SISO to accomplish the task will not achieve this goal in the long term without a strong Government recommendation. For this effort to truly succeed, it will require collaboration among academia, industry, and government.

6. RECOMMENDATIONS TO MAXIMIZE SIMULATION REUSE ACROSS DOD

To establish a unified approach to maximize simulation reuse, the DoD needs to strongly recommend a standard response from industry.

6.1. DoD best practices and provisions

The DoD's best practices for M&S must include provisions for three broad areas:

1. Model Sufficiency
    a. Are high-fidelity models available?
    b. Are they compliant with interoperability standards?
2. Tool Usability
    a. Need tools that highly automate the M&S process
    b. Software tools must be easy to use, easy to learn, and fast
3. Process Adoption
    a. Need usage to get credibility and continuous improvement
    b. Write model deliverables into contracts
    c. Make model repositories easily searchable

6.2. Recommend wider deployments of existing efforts

The adoption of simulation-based processes and toolsets in the defense space will gain the most traction when recommended with ongoing efforts.

For example, existing programs such as OneSAF should publish their plan on how they will interoperate with new models. The next evolution of OneSAF should incorporate higher fidelity simulations of FCS models, which may already exist.

Since OneSAF is expected to be a platform for other services if it continues to be successful, this should trigger a number of action items including: discovering needed models, identifying interoperability protocols, and designing necessary extensions to incorporate OneSAF into new programs.

6.3. Employ a bottom-up approach to unifying simulations.

Experience shows that a bottom-up approach to unifying simulations is superior to a top-down approach. For example, the expansive JSIM project that preceded OneSAF failed due to the management burdens of operating as a joint-service project.

6.4. Account for ongoing simulation interoperability efforts.

A unified approach relies on simulation interoperability. The DoD should consider how ongoing infrastructure developments in the DoD community will fit in. These efforts include HLA, BOMS, SEDRIS, and MSDL (Military Scenario Definition Language).

The products from these community efforts include new standards and conventions for adapting modern simulation methods, as well as adapting legacy models.

6.5. Populate government-owned model repositories. Let industry maintain proprietary repositories with interface-based model access.

The principle of "garbage-in, garbage-out" dictates that achieving highly accurate simulations requires access to more accurate data. When access to existing high-fidelity models is restricted or not available to Government engineers and contractors, the overall quality of simulations in the DoD community suffers.

This recommendation gives both the DoD and industry access to models while protecting their intellectual property. The DoD would allow contractors to interface with decentralized repositories based on service contracts, similar to the way that DMSO sponsors M&S efforts such as SEDRIS. This policy will provide Government engineers and support contractors more accurate models and data to use.

6.6. Establish a validation program for simulation models.

A validation program is necessary to verify the adequacy of simulation models. This program can be run by a university center, the way Johns Hopkins was contracted to perform HLA RTI compliance testing for DMSO.

6.7. Invest in a standard simulation-based design environment.

Investing in a standard simulation-based design environment will enable the DoD to send a tangible recommendation to its PEOs and contractors. DoD will want to identify a software toolset that is easy to use, accurate, useful, and flexible.

6.8. Require the delivery of component models developed under contract.

To execute this recommendation, the Government and its contractors will need standardized tools to handoff and evaluate models. The DoD will want more automated M&S capabilities to get more ROI, and should survey the market for better tools to effectively manage M&S.

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8. BIOGRAPHY

KEVIN TANG is a Research Engineer at Cybernet on the Virtual Systems Integration Lab (VSIL) program for TARDEC: an advanced modeling & simulation toolset to accelerate systems engineering trade studies. Mr. Tang co-designed and built the earliest prototype of the Virtual Systems Editor (ViSE) tool used to automate component trades of multiple vehicle configurations. He holds a BSE in Computer Science and Engineering from the University of Michigan.

GLENN BEACH serves as the Director of Technology for Cybernet and is Principal Investigator of the Virtual Systems Integration Lab (VSIL) for TARDEC. Mr. Beach has extensive experience in creating innovative products by integrating software and hardware into a cohesive system. He has developed an expertise in many areas of hardware integration and software development, including machine vision, networking, and decision theory. He holds a BSE in Engineering Physics from the University of Michigan.

CHARLES COHEN has been working in the fields of modeling and simulation, image processing, robotics, human-computer interaction, and artificial intelligence for over a decade. He is currently the Vice President of Research and Development for Cybernet Systems Corporation. He has been the project manager for many projects for the United States Armed Forces (Air Force, Navy, and Army), National Aeronautics and Space Administration, and other government agencies. Dr. Cohen's current research interests are in gesture recognition, image processing, estimation theory, system integration, visual communications, machine vision, and perceptually coupled systems.

RYAN O'GRADY is a Research Engineer at Cybernet for the Virtual System Integration Lab (VSIL) for TARDEC. He has experience with large-scale system design and has been integrally involved with the design and development of the VSIL and ViSE software. Mr. O'Grady continues to refine the tools available and add to the system and toolset. He holds a BSE in Computer Science Engineering from the University of Michigan.

RUDY RODRIGUEZ joined Cybernet in May 2006 as a member of the company's VSIL group in order to expand and support development of the VSIL libraries. Mr. Rodriguez worked several years for General Dynamics Corporation at Sterling Heights Michigan, in the Vetronics Integration Labs of the M1A2 Abrams tank program. He worked extensively with multiplatform M1A2 Abrams Test Benches as well as other military vehicles. In this capacity he was responsible for maintenance and repair of both the vehicles and test benches used for software and hardware testing, and also for performing system modifications to the test benches and vehicles.

STEVE ROWE is Chief Software Engineer at Cybernet Systems Corporation in Ann Arbor, MI. He is the technical lead for the development of the VSIL software suite. His software development experience spans over 20 years in diverse fields such as space flight control systems, industrial automation, scheduling/resource management systems, artificial intelligence systems, and robotics. Recent work has included the creation of the OpenSim™ toolkit, the

Simulation Execution Environment of the VSIL, and interfacing technologies for HLA, J2EE, and DIS.

RAKESH PATEL is acting Associate Director for Power Systems at Ground Vehicle Power and Mobility, TARDEC, RDECOM. He is leading the advancement of the vehicle prime power generation, non-primary power systems, vehicle thermal management, electrical power management, and electrical power distribution related technologies. His engineering work experience at TARDEC spans fifteen years in the following organizations: Ground Vehicle Power and Mobility, Next Generation Software, Intelligent Systems, and Vetronics Technology Area. He holds his BSEE from University of Illinois and MS in EE/CS from Oakland University. He is a member of the Army Acquisition Corps.

JASON UEDA is currently an associate on the Powertrain Modeling and Simulation Team, under the Ground Vehicle Power and Mobility organization for the Research Business Group, at the TARDEC-RDECOM in Warren, MI. He currently supports developmental engineering projects involving hybrid electric vehicle propulsion modeling for the Ground Vehicle Power and Mobility Research Business Group at TARDEC, RDECOM. He is a member of the Army Acquisition Corps.

ERIC JOCHUM is a computer engineer on the Non-Primary Power Systems Team at TARDEC, RDECOM. He is technical lead on the Power Architecture, virtual system integration laboratory, electrical power management, and computing hardware. His engineering work experience at TARDEC spans seven years in the following programs: Advance Mobile integrated Power System (AMPS), Hybrid Electric Vehicle Evaluation and Assessment, Power and Thermal Management ATO and WSCOE. He holds his BSE in Computer Engineering from Western Michigan University and his MSE in Computer Engineering from University of Michigan - Dearborn. He is a member of the Army Acquisition Corps.

SYED MOHAMMAD is a Project Engineer at the US Army's Tank-Automotive Research Development & Engineering Center and currently supports the Intelligent Ground Systems (IGS) and Joint Center for Unmanned Ground Vehicles (JC-UGV) technology areas. His interests are in interoperability and distributed simulation architectures, and management of large scale simulation activities. Syed holds a B.S.E. in Computer Engineering and an M.S.E. in Industrial and Operations Engineering from the University of Michigan at Ann Arbor, and is currently pursuing a Ph.D. in Modeling and Simulation from the University of Central Florida at Orlando.